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The Effectiveness of Cost-Effectiveness Studies in  
the Context of AMC Decision Making\*

by

Donald Belfer  
Philip DeSantis  
William Putt  
Michael Scott-Morton  
Zenon Zannetos

Working Paper 369-69  
February 1969

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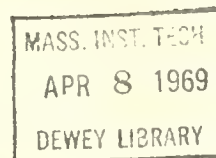


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January 9, 1969

This is a final report on the first phase of AMC Grant DAAG 39-68-C-0015 under the direction of Zenon S. Zannetos. The authors wish to acknowledge the able assistance of Messrs. Donald Baron and Dennis Meadows of MIT, Sloan School of Management and the many people within the AMC who graciously spent whatever time we demanded out of their busy schedules.



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## I. Introduction

In recent years schools of management and industrial managers have focused their attention on the development of quantitative approaches to management problems. Inventory control, production scheduling, capital budgeting, cost-effectiveness analysis and other areas have been the principal beneficiaries of this effort. Although we have numerous reports of successful implementation, it is generally true that the theory has outstripped our capability to implement these techniques.

This report examines the implementation of cost-effectiveness analysis by the Army Materiel Command. Specific attention has been focused on the interface between the quantitative methodology and the user of the analysis results, the decision maker. Successful implementation depends upon a successful coupling at this interface. The coupling mechanism between the decision maker and the analyst who applied the methodology is the information flow, formal as well as informal, between them. Consequently, much of the discussion to follow will deal with methods for bringing the needs of the decision maker to bear on the objectives of the analyst, with the methodology itself, and with the role of the information system requirements in such context



## II. Objectives

The title of this research is "The Sensitivity of Management Decisions to Quantitative Models and Methods for Improvement in Such Models through the Management Information and Control System". This title reflects the general objectives chosen for the project. The intent was to satisfy both the interests of the Army Materiel Command and the Management Information and Control groups at MIT. In approaching our research we delineated eight subsidiary objectives. These were:

1. To examine the sensitivity of decisions to quantitative analysis. That is, to examine the effect of cost-effectiveness studies on management decisions, and to understand the role of studies in the larger decision process.

Specifically, we were interested in whether or not cost-effectiveness studies have a major influence on the decision makers in the execution of their responsibilities. Studies may merely confirm or substantiate the decision maker's initial judgement, or be the sole determinant of the decision, or may combine the decision maker's value judgements and the many objective factors into the decision analysis.

2. To examine the role of the decision maker in a decision process which is based on quantitative analysis and to determine in what way his time can most effectively be applied to the systems analysis. There are numerous contributions which a decision maker can make at the beginning of the study, during the execution of the study, and in the



interpretation of the results. We were interested in the effectiveness of the decision maker's participation in each of these areas.

3. To recommend ways for improving the consistency between the objectives of the decision maker and those pursued in the study. In many cases, quantitative analyses tend to answer questions which are either framed in different terminology than that of the decision maker or, in fact, answer different questions than the decision maker had in mind.
4. To recommend ways for improving the timeliness of the study results by reducing the elapsed time between the request for information and the completion of the study. Success in this area would also reduce the disruption of the analytic process to reasonable bounds.
5. To suggest methodological approaches to the systems analysis in order to provide more flexibility and enhance its utility to the decision maker. Methodological approaches can become over quantitative and rigid attributes which may constrain their application and usefulness.
6. To recommend ways for increasing the decision maker's contribution to the interpretation of the results of systems analysis studies. That is, suggest methods by means of which the decision maker can impart his judgements and values, as inputs, to the SA findings. Many times, in a study, significant value judgements are made that do not necessarily represent the values of the decision maker. It was our objective to find ways of insuring that the value structure of the decision maker was strongly represented in the interpretive process.





7. To improve the overall efficiency of the study process, both in terms of goals and methodology, through the management information system. To propose new information systems to complement the present managerial system and provide feedback for efficient and effective management. From the identification of a problem, to the recommendation of a solution, to the action taken with respect to that recommendation, there are many information sources and channels which must be considered for the most effective decision making process. Consequently, it was our intention to find ways of improving the efficiency of this communication process.
8. To suggest ways for increasing the transferability of benefits from studies. Beyond the decision oriented recommendations of a study, there is a large amount of significant, widely applicable information, such as:
  - . New Data
  - . New Methodology
  - . Subsidiary weapon concepts
  - . Criteria for measuring decision quality and future performance

A study built on sound methodology, updated to reflect the current state of knowledge (in terms of data, analytical methods, and environmental assumptions) and properly classified for easy access, can serve as an invaluable source document for future needs. We wanted to examine ways of transferring this knowledge to other relevant situations.



### III. Assumptions

To put these objectives in the proper framework and to describe the basis for our study methodology, it is necessary that we delineate our study assumptions. We assume that:

1. Top managerial and decision-making talents exist. The major aspect that limits the scope of these talents is the inability of the decision makers: (a) to cope with the large amount of unstructured data, i.e. this inability is mainly due to the lack of time and, to a lesser extent, to the lack of methodological expertise to digest, organize, filter, condense, evaluate and extract information out of the mass of relevant and irrelevant environmental data (b) to readily change the structure of the decision system, as dictated by environmental changes.
2. In order to be able to cope with both data and adaptively changing environments, the manager must know enough about relevant theories, methodologies and systems analysis, and about the tools used, to appreciate the power and limitations of the technology and become the interface between the tools, the methodology and the decision situations. This, however, does not imply that the decision maker must be an expert technician or system analyst himself.
3. The decision maker should be able to derive the necessary information needed for the decisions he faces, from the following:



- a) the study objectives
  - b) the assumptions which impinge on the data and the methodology used
  - c) the description of the methodology used
  - d) the description of the critical parameters considered and how they constrain the results
  - e) the results and conclusions
4. The decision maker is a planner, not a fire-fighter. Therefore, the greatest payoff for his time investment will come, if it is spent on the definition and planning phases of the study process and on the provision of control to the individual studies. In this way he will not have to monitor continuously the critical environmental assumptions which affect the objectives of the studies and the study process itself. The information system will provide him with signals, if the critical assumptions on which he bases his plans are violated, indicating a necessity for replanning.
5. Through a management information system, signals can be generated to complement the decision maker's personal supervision and also provide preventive causal diagnosis.
6. The decision maker has sufficient authority to implement changes in the present system and the present study process
7. Learning from successive cost-effectiveness models is possible and the transfer of these benefits is desirable.





#### IV. Theoretical Framework

Planning and control theory suggests that the formalization of decision models is necessary for learning and sequential adaptation to changes in the environment.

In particular, with respect to planning, there is a lot to be learned from experience if, somehow, we could capture, document, evaluate, and preserve it for later use. The fact that each particular planning opportunity appears to be unique has prevented the appreciation of another fact, that planning processes have many elements in common irrespective of the particulars of the setting to which these are applied.

Unfortunately, within most organizations, planning is carried out as an ad hoc activity and completely divorced from the on-going information and control system. This practice encourages undue reliance on intuition, and memory, and at the same time ignores the presence of a framework which can aid learning. The latter can occur through the discovery of new patterns of relationships, and in the process of review of the various assumptions, and the cause-effect relationships underlying the various elements in the planning process. A formal linkage between an explicitly stated plan and the on-going information and control system will ensure that the data, which are necessary to validate and implement the chosen plan, are collected. At the same time, this linkage will allow a review of the whole process so that the organization may learn from experience.



It is for the above reasons that we consider formal planning and decision making a necessity. As used here, formalization includes at least three elements:

- (a) The explicit statement for any plan of: the critical underlying environmental assumptions; the dominant cause-effect relationships; the consequences of such on the critical decision which have to be made and on the operations which are necessary to carry out the plan; the definition of the necessary signals or indicators which will provide managers with the timely feedback for replanning; and the details of the measurements which will generate the indicators. (always bearing in mind the sensitivity of management plans and decisions to the refinement in these measurements)
- (b) The definition of the information and control system which will apply the measurements and generate the indicators which will facilitate learning, planning, and control on an exception basis.
- (c) The mechanism for a formal review and replanning procedure at regular intervals. This procedure will guarantee that:
  - (i) A plan for planning exists, and that this plan is not solely dependent on the signals generated by the information and control system.
  - (ii) The search for planning alternatives is not limited to variations of existing plans.

To summarize then, formalized planning in our terms, imposes a discipline for explicit recognition of alternatives, assumptions, cause-effect relationships and the consequences of such, on managerial decisions. It also forces on the manager some rationality and consistency in dealing



with alternatives and going through the various steps in the planning process. It provides for the definition and generation of information to facilitate replanning, and it ensures the manager an opportunity for reviewing the total process. All these attributes of formalized planning are very conducive to learning from experience. Finally, the link between plans and the on-going information system provides organizations with a unique opportunity to store planning intelligence and to facilitate the transferability of planning knowledge.

In the context of this project, formal models are necessary because:

1. The decision maker is faced with large quantities of raw data in unstructured form which must be analyzed, filtered and condensed. Without a framework, it will be close to impossible to create a semblance of order out of chaos.
2. The decision maker needs to have access to adaptive models of the world against which he can test alternative plans. The explicit recognition of environmental assumptions and the underlying cause-effect relationships will facilitate the testing and evaluation of alternatives.
3. The system must provide timely response to the changes which occur in the planner's model of the world. This can be accomplished if critical assumptions are monitored and deviations from acceptable norms are reported to the manager.
4. Specific statements of cause and effect relationships are necessary for preventive diagnosis. A formal system, not only explicitly states such critical cause-effect relationships, but also provides a link between plans and the management information system. The signals generated by the control system can be further amplified to include consequences of projected deviation from expected norms.





5. Transferability is achieved if there is standardization of data format, classification of models, hardware, software and management information systems. It has been already stated that the formalization of plans, and the linking of such to on-going information and control systems, provides among other advantages a unique opportunity for pattern recognition and the development of organization-wide intelligence. Some other consequences of such a successful linkage will be the determination of the necessary input data for testing and implementation of the models, and also the standardization of terminology, of classifications, and of query languages.

We must admit that the road leading to the formalization of planning models and the linking of these to the managerial information and control system are not completely free of problems. One must be prepared to overcome:

- (a) The aversion of people to state explicitly their assumptions and thought processes, because of fear that later history may prove them wrong.
- (b) The possible tendency of model builders to use complicated methodological approaches which are either, unnecessarily complex, or little understood by the users of these models.
- (c) The difficulty of validating models both with respect to their structure and the relevance of the parameters.
- (d) The problems inherent in updating models and their re-use.
- (e) The difficulties involved in developing relevant input data to a control system of formal plans, and resolving all the issues associated with the timing of replanning activities.



On the basis of our research under this project and the elucidation that it brings to some of our prior experiences, we are motivated to say that, the major problem with formal models, is not so much with the models themselves (methodology) but in the difficulty of providing an adequate decision maker-model interface. There are, of course, many facets to these interfaces. Any formal system must involve the decision maker, the model itself, the analyst, and the data base required by the objectives of the planning process. If the interfaces between each of these components are not designed properly, the decision process will no doubt suffer. In addition, in many real situations the model has to be constructed and this may involve technicians of various specialities. In a real dynamic environment then, in addition to the interface problem between such systems analysts and the rest of the components mentioned above, there is a further problem of successfully resolving the interfaces between model builders themselves.

Because of the above reasons, and in the context of most AMC needs:

1. Models must allow the decision maker to readily test various values of parameters. They must also permit and facilitate choice of the level of output.
2. Models must specify the parameters and the various threshold constraints that are critical for decisions, so that the decision maker can introduce his value system by choosing among these factors.
3. Models must monitor the critical relations between the environment, the objectives, and the task, and also incorporate in them the ranges over which critical values of these can vary without affecting the decision situation.



4. The critical cause-effect relationships, some of which are implied under Point 3 above, must be explicitly stated to capture as many of the dynamic aspects of the modeled situation as possible. In this way, the decision maker would be able to use the model as an active tool in exploring his problem and the alternative solutions to it.



## V. Criteria of Study Effectiveness

One of the first needs recognized by the study group was to develop some criteria by which the various studies, made available to us could be evaluated. We were unable to do this except on a very rudimentary basis at the beginning of our study. We ultimately developed, however, seven criteria for evaluating the quality and utility of the cost-effectiveness studies. It should be emphasized that our viewpoint was quality and utility from the standpoint of the decision maker. Other viewpoints such as the elegance of the solution or other similar criteria had little bearing in this study.

The first criterion is the time required for the decision maker to comprehend the essence of the analysis. If a decision maker is to make a decision based on the analytical efforts of others, he must be able to comprehend the nature of the analysis which they have made and to do this in significantly less time than it took those who performed the analysis. Specifically, the decision maker must not be required to read and evaluate all aspects of each study.

The second criterion is the relevance of the study to the decision which must be made. Needless to say, a study which answers questions unrelated to the decisions which must be made has little value. For example, if a decision maker must make a procurement decision, a study which shows only that the particular kind of truck is better under certain circumstances than all other kinds of trucks, and not the quantity to be procured, is deficient.





The third criterion is the amount of information required to make a decision beyond that provided by the study. One of the traps into which an operations analyst can fall is treating only those parameters which are susceptible to quantitative analysis, leaving the qualitative parameters to the decision maker and others for input and evaluation. Treating these qualitative parameters after the systems analysis can lead to a follow-on study as large as the original one.

The fourth criterion is the timeliness of the results of a study. In most cases a decision must be made at a certain point in time even with incomplete information. If, for some reason, a study is inadequate and revisions must be made, the making of the decision will necessarily be delayed. If this delay continues, new alternatives, and new projections of the enemy's threat must be re-evaluated, creating obsolescence in the original objectives of the study.

The fifth criterion is the ease with which the study can be revised. While it is possible for a decision maker to specify at the beginning those questions which he wishes to be answered, many considerations change in the process of performing the study. New problems and questions arise making some revisions in the study desirable. Ease of revision might be measured in terms of the time required to revise the study, the cost required, and the useability of the old computer programs and routines developed for the original study. In any event, in conducting and evaluating any series of studies, it should be recognized that not only in the short term when the decision maker is considering the study for the first time, but also



in the longer term, there will be constant needs for revision. These needs should be reflected in the choice of study methodology and the mode of presenting the results.

The sixth criterion is the ease in making parametric changes and asking questions of the model. Most decision makers will need to ask certain questions which are not specifically answered in the presentation of the results. Principally, this is to enable them to understand the structure and relationships within the model and the sensitivity of the results to a change in the assumptions.

The seventh criterion is the methodological appropriateness. It is possible that in some studies methodologies too complex or too simple for the problem will be used. In economics we use a criterion of simplicity to choose between models. Perhaps a similar criterion is also valid in the systems analysis area.



## VI. Study Procedure

### Analysis of the Problem

The study was initiated with a series of round table discussions in which various objectives and study approaches were considered. Relevant sources of literature were also sought at this time. After a reasonable period of time during which the study team was built and some tentative ideas developed, discussions were held with General Bunker.

After these discussions, it was decided to examine the cost-effectiveness process from the viewpoint of its information systems. Specifically, we chose to look at the interfaces between the analysts, the study itself, the experience from previous studies, and the decision maker. We also wanted to examine the impact of the methodology on the information process.

### Pilot Study

In order to gain a broad perspective of the study process, it was decided to examine a large sample of studies. To sharpen our approach, a pilot study of the "Effectiveness Comparison of 4.2 Mortar Ammunition M329A1 vs. XM571" and the "Cost Performance Analysis of M656, M520, M542A and M548 Vehicles" was undertaken. From the information learned in these studies, a series of hypotheses (see attachment 1) were developed for the larger analysis, and a questionnaire was developed to test these hypotheses (see attachment 2).



### Full Scale Study

Using the following general criteria, and with the aid of Tom Shirata, we selected the studies which appear in attachment 3 for analysis.

- . Completed rather than in process studies
- . Completed sufficiently recently that personnel can still be interviewed
- . Weapon procurement studies rather than strategy studies
- . Include various types of study groups--industry, project manager, experienced in-house study groups, etc.
- . Of different cost magnitudes and depths of analysis.

The studies were sent to MIT where they were read. Interviews were then set up with the study manager and where possible, the cognizant review agency and the decision maker. Interviews lasted from 45 minutes to an hour and a half. The questions in the questionnaire were first asked and then some time was given to free discussion.

### Analysis

The first analysis approach which we undertook was descriptive. A decision model, a document flow model, and an organizational flow model of the process, as we observed them, were developed. Each of these was analyzed and then an improved decision model was developed.

Our second analysis approach was the quantitative analysis of the questionnaire data in which two basic steps were taken:

- . Studies were ranked on the basis of quality
- . This measure of quality was used as a basis for testing our hypotheses about study effectiveness.





The quality ranking was developed by employing the best operational measures of the criteria of effectiveness<sup>(1)</sup> which we had available.

These measures were:

- (1) Was the study re-done?
- (2) Was the recommendation of the study followed by the decision maker?
- (3) Was the structure and presentation of results of the study rated high or low? (In essence, we evaluated the content of each study to determine whether or not all the elements which a decision maker might search for in a study were easily identifiable. The studies were then split into two equal categories--elements were easy to find, elements were difficult to find.)<sup>(2)</sup>

Each study was given a point score of 0 or 2 for the first two criteria and of 0 or 1 for the third criteria. These ratings were augmented by overall study evaluations for nine studies which were obtained from AMC personnel. If the study was considered good, it received 2 points. If it was poor, it received 0 points. The overall subjective evaluations agreed well with the three objective measures. Where data was missing, a 0 was given. The scores from each of these criteria evaluations were then summed to form an overall ranking index. Based on this index, the studies were then split into four categories, excellent, good, fair, adequate. All the studies in each category were about equal. (see attachment 4 for the ranking). There

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<sup>1</sup> See section on criteria of effectiveness.

<sup>2</sup> See Findings of the Interface section for a more thorough discussion of this point.



are a number of deficiencies with this ranking of studies, both in the measures which were used and in the data which in some cases was incomplete. However, this did provide some measure for evaluating our hypotheses.

We next ran Spearman rank order correlations between our hypothesized causal parameters and the just described effectiveness measures to test our hypotheses.

The third analysis approach was interpretation. We had collected a great deal of notes and written material which favorably supported and suggested improvements for the system. We tried to take this material and integrate it with the two above analyses as well as with our own theoretical knowledge and draw out those other findings which seemed important.

Finally, we examined the study methodologies through reading the studies, drawing from our interviews, and examining how this methodological structure might be made more compatible with the decision maker's information needs.



## VII. Findings and Recommendations

### (A) Interface Analysis

#### Introduction

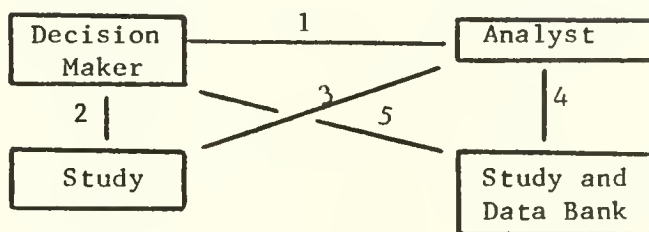
Cost-effectiveness analysis is not entirely a new innovation in the evaluation of trade-off decisions. Significant applications of this methodology were made during the Second World War, and, with the passage of time, managers have found the technique more and more useful. As the application has broadened, managers have formed task groups whose specific functions are to undertake these more sophisticated and complex analyses. In the early days the decision maker typically kept his staff very close to him and made significant contributions to the analysis itself. As time has passed, however, the necessity for these studies has grown considerably. To accommodate this demand, autonomous organizations have been created specifically to undertake these studies. With the advent of this specialization and autonomy from the decision maker, the study process has changed. New communication channels and technical interfaces have been created and analysts have begun to assume power that previously belonged only to the decision makers. The decision makers role has tended to become more one of initiating studies and acting on their recommendations. Meanwhile, the analyst has become a distant interpreter of the decision maker's needs and judgements, and a practitioner of the new complex decision technology.

This new structuring of the process seems to have resulted in the studies becoming less responsive to the manager's decision requirements, both in terms



of timeliness and adequacy. In this particular section, therefore, we have chosen to directly examine the interface problems in the present day study process. As can be seen from the figure below,

Interface Model



there are five very important interfaces which must be considered in the current study process.

The first (1) is the interface between the decision maker and the analyst. Here the concern is with the transmission of the decision requirements, the study objectives, and the relevant value judgements from the decision maker to the analyst. Too often perhaps a directive of several pages is thought to be sufficient.

The second (2) is the interface between the decision maker and the study. If a decision is to be based on a complex analysis, some understanding of the assumptions, the relationships, and the sensitivity of certain parameters must be transmitted from the study to the decision maker without the decision maker having to re-create the complete analysis of the systems analyst. This is particularly true when the problem involves multiple alternatives





and multiple criteria of effectiveness. In these cases flexible methods of presentation, which allow the decision maker to contribute his own value judgements, must be employed.

The third (3) interface is between the analyst and the study. As data becomes more voluminous and solutions require greater computation, the analyst must construct his models and carry out the study with the aid of the computer. His interactions with the study are through a terminal or through a computation center. As a consequence, he is concerned with such things as turnaround times, program formats, program diagnostic capability. Improving these interfaces are important in improving the efficiency of the analyst and the quality of the final study.

The fourth interface (4) is between the analyst and the organization's stock of experience, i.e., the bank of previous studies and models and the bank of current data. As multiple agencies and organizations engage in the preparation of cost-effectiveness studies, experience is developed with potentially wide application. If, however, methods for collecting this information and disseminating it to the other analysts are not developed, no long-term learning will develop in the study process. Thus, attention must be given to the interface between the analyst and the existing store of knowledge.

The fifth interface (5) is between the decision maker and the study and data bank. Frequently the decision maker will wish to compare the results, assumptions, and approach of a current study with those of some previous studies. Existence of a data file and ability to search it first by



report titles and then by abstracts will be necessary for such a comparison process. From the information drawn from the storehouse of previous knowledge he can ensure the latest findings and approaches are brought to bear on each study.

### Findings

The findings which we will discuss here relate primarily to the interface problems just described. They are presented here, followed by the factors which led us to believe that they were important and constructive.

In reviewing these findings, the reader should keep in mind the limitations of the sample size of twenty studies. Statistical and numerical inferences should be considered only as suggestive of trends. To interpret these findings, one should also consider the specific studies which were included in the sample since they establish the representativeness of the study.

#### Finding 1

In analyzing the decision-maker-analyst interface, it was found that the decision maker's participation in the study process would appear to be more effectively allocated if a greater proportion of his time were concentrated in the early phases of the study. At the present time, the decision maker's attention is focused almost exclusively on the final report, the very end of the study. By this time, the study structure has often become rigid and cannot easily be revised to reflect the particular interests of the decision maker. To avoid this fait accompli, it would appear more efficacious if the decision maker considered with the analyst the objectives of the study and the preliminary proposal for performing this study.



There were five basic points which led us to this conclusion. First, at least half the studies which we examined had to be re-done after the review of the final report by the decision maker. As a consequence, the time spent by the decision maker on these studies was at least doubled because he had to review two or more final reports. In several cases, there were more than two reviews. It would seem that, if the decision maker could participate earlier in the proposal, or study execution process, some of these reviews might be avoided. There is even a potential for a decrease in the decision maker's participation time as well as an increase in the general quality of the studies.

The second point which led us to believe that earlier participation by the decision maker might be more effective was that studies were of higher quality in which there was some form of proposal review, regardless of whether it was a decision maker or his immediate representative. The criteria of quality is that which is referred to and described in the section on criteria of effectiveness.

The third point was that the principal dissatisfaction expressed by personnel at the decision maker level was that studies were not responsive to the problems which they were facing. In particular, the questions which were sometimes answered by the studies were not the questions which the decision maker wished to address. Further, the information required for some decisions was not always developed in the study process. It was this concern which led to the initiation of this study.



The fourth consideration was that, for those studies which had to be reviewed or re-done, over 70 per cent of the reasons given for revision were due to factors related to the decision maker's judgement rather than to methodological problems. In general, there were very few studies re-done or revised because a computational or methodological error was found, or because new data was introduced. In most of the cases, the reason for revision was because the decision maker desired other conditions to be examined, other alternatives to be examined, or new interpretations of the results to be made. Some of these evaluative revisions could probably be identified earlier in the study process, thus avoiding the wasted or inefficient effort which goes into the revision process.

Fifth and finally, the late intervention by the decision maker appears to be introducing an effect which the decision maker himself felt was undesirable. In particular, at the analyst level, there is a general feeling that higher headquarters desire each study to be more sophisticated, more complex, and employ a newer methodological approach than the previous study. On the other hand, our discussions with headquarters decision maker representatives revealed a desire for simpler less complex models. The reason for this misunderstanding appears to be that the decision maker desires a greater generality or ability to respond to "what-if" questions while the analyst anticipating many "what if" questions had tried to provide built-in answers, thus increasing complexity and sophistication. Earlier participation by the decision maker, therefore, might lead to a greater mutual understanding of the level of analysis which is appropriate to each problem.





## Finding 2

Again, with respect to the decision-maker-analyst interface, great attention should be devoted to the definition of the decision which the decision maker must ultimately make. While increased emphasis has been given to identifying objectives and specifying the problem, there do appear to have been a number of instances in which the decisions to be made still were not either clearly understood or if understood, not adequately incorporated into the study. The definition of the decision must be stated in operational terms so that it is meaningful to the analyst. It is a mistake to say that non-responsive studies are always the fault of the analyst. They may, in fact, be the fault of the decision maker for not accurately specifying exactly what decision he must make and for relying on the analyst to develop, not only the information required for the decision, but to develop the decision at hand as well.

Several factors led us to believe that this was an important area. First, on the average, four separate distinguishable organizations review and interpret the study objectives before they reach the study analyst. It is not surprising, therefore, that by the time the analyst receives these objectives they do not necessarily reflect the decision needs of the ultimate user of the study. The organizational distance between the study analyst and the decision maker is extremely long.

A further problem in aligning the study with the needs of the decision maker is that in general, at least two, and as many as five organizations have responsibility for the preparation of the study. Each brings a different point of view to the same problem. In most cases the organizations performing the study are equally distant organizationally from the decision



maker. This makes a ready territory for the compromise of biases at the sacrifice of the decision maker's real goals and value judgements as they may have originally been expressed in the study objective.

Third, there are a similar number of intermediary organizations which review and revise the results of the study. These again produce a filter between the study analyst and the decision maker, with respect to the interpretation of results found in the study analysis.

Fourth, it is the general impression of the study analysts that they make a number of calls and hold copious conversations with people at the decision maker level, so that objectives are adequately interpreted. On the other hand, discussions with decision makers and members of their staff reveal that they do not believe that analysts do adequately communicate with the decision maker. This misunderstanding would appear to be indicative of the communication problems that exist between the analyst and the decision maker.

### Finding 3

The final consideration in the decision-maker analyst interface area concerns the facilitation of communication between the two.

The policy oriented decision maker appears to have some difficulty, as might be expected, in discussing issues with the technically oriented analyst. This communication issue is not only a matter of language and semantics but also a matter of the outlook and background of the personnel involved. Increased time on the part of the decision maker in defining his problem early in the model formulation process would undoubtedly help. In the cost-effectiveness studies that we examined, it was noted that the model did not form an effective communications medium between the analyst



and the decision maker. One way of helping with the communications problem would be to have both parties talking around some common structure of some specific variables. That is, the semantic problem is reduced as conversations become more and more specific. However, the technology and the model methodology that is currently being used in the studies that we examined is not such as to provide this communications vehicle. The models were all extremely detailed, and the technology did not allow testing of even portions of the model in any flexible way. As a natural outcome of this, the review committees that sit and examine the methodology and other issues surrounding the technical aspects of the model are not able to provide a decision maker with an intermediate source of review. That is, a technical review progress committee has to be technically oriented if they hope to understand and comment effectively on the technology involved in each of the models. This group, however, has exactly the same problems in communicating with the decision maker as the analysts themselves.

#### Finding 4

Turning now to the interface between the decision maker and the study, we found that there is little consistency in the presentation of study results. At the present time, the decision maker must read between ten and thirty studies a year. Consequently, with this expenditure of time in a repetitive activity, it becomes important to examine the factors which affect his ability to comprehend and make meaningful decisions from study reports with the minimum expenditure of time. The development of a minimum standard set of components with common definitions of terms would significantly decrease the time required for the decision maker's evaluation of the study.



The factors which led us to this conclusion were that a review of the twenty studies which we evaluated revealed a radical difference in the terminology employed and in the report organization structure. There was almost no similarity between tables of contents. Further, similar words in different tables of content designated different elements of information. Under such circumstances, it is obvious that the decision maker cannot quickly go to the table of contents, search out, for example, the assumptions, the conclusions, criteria of effectiveness and find the information which he seeks.

The second point arose from the examination of a set of 25 information components in each study which we felt were necessary for ease of comprehension. These components were:

- (1) the documentation which led to the initiation of the study
- (2) the identification and description of the study team and its organizational relationships
- (3) the cost of the study
- (4) planned and actual schedule for the study
- (5) the definition of the decision to be made by the decision maker
- (6) a statement of the study's objectives
- (7) ground rules and assumptions employed in the study
- (8) the alternatives considered in the study
- (9) the criteria of effectiveness employed in the study
- (10) the sources of data used in the study
- (11) the prior studies relevant to the study





- (12) the approach used in the treatment of risk and uncertainty
- (13) the limitations and the exclusions of the methodology
- (14) the dimensions of the cost breakout
- (15) a flow chart of the model used in the study
- (16) a description of the model used in the study
- (17) the major parameters employed in the model
- (18) the structure of the integration of the multiple measures of effectiveness
- (19) the structure for the integration of cost with the multiple measures of effectiveness
- (20) the major sensitivity and contingency analyses carried out
- (21) the relationship of the analysis results to the decision to be made
- (22) answers to the specific questions posed by the decision maker
- (23) a matrix of the multiple measures of effectiveness versus the alternatives
- (24) recommendations for methodological improvement
- (25) an analysis of the specific qualitative factors not covered in the quantitative analysis.

Our analysis of the ease of finding each of these elements in the different studies showed that in less than half of the studies were each of these elements easily found. Unfortunately, there was little consistency in the ability to find all of the elements in any one particular study. Rather, studies tended to have half of the elements well presented and the other half poorly presented. The clear consequence of this is that the decision maker must read each study as new and entirely different from all



the rest which he has read. He must read it in its entirety to be sure first, that he gains all of the information present and secondly, to find out what information is not contained in the report. A standard set of components uniformly understood and presented might significantly reduce the decision maker's time input to each study.

#### Finding 5

The decision maker's interaction with the cost-effectiveness model is limited, at the moment, to printed material and verbal exchanges between the analysts and the decision makers involved. The models are typically, extremely complex, and the printed page does not do justice to the kinds of relationships and assumptions that have been built into the model nor indeed for the implications of these assumptions on the decision at hand. Quite apart from the variation in the presentation and preparation of the reports which is discussed above, there is the issue of static versus dynamic information presentation. Certain concepts and assumptions are not easily understood unless the decision maker is able to see some time trace of the variables involved or has been actively involved in the construction of the model itself. Since the decision makers have very limited time, it is not surprising to find no instances of active decision-maker involvement in the model construction process. However, this does imply that the decision makers are not really conversant with the model itself at the moment of decision.

Similarly, the structure of the models which we examined were designed to implement the analyst's notion of the appropriate analysis for solving



the problem as he perceived it. Due to constraints in time and budget, the analysts did not appear to have time to develop parameterized models for the decision maker's use. The parameters that were available for the decision maker to change, typically did not reflect the kinds of parameters he wanted to change, and the result was that the study had to be re-done, rather than simply re-run with different data. Similarly, the decision maker did not have the ability in any of the cases we examined, to alter the structure of the model itself without the necessity of going through the whole rebuilding of the model. The decision maker did not have the ability to modify the parameters of the model with a given structure, nor did he have the ability to modify the structure itself. In many of these very complex models, this ability may not realistically be available on any large scale, but the studies, decision makers, and analysts involved in the cases to which we had access, did not identify to the researchers any concern with this problem or any notion that there could be some marginal improvement on these issues.

#### Finding 6

The third interface was between the analyst and the study. In this area, we found that many of the models were written in different languages to run on different computers. These models were often incompatible with data structures and data bases which had been set up from previous studies. All of the equipment involved runs in a batch mode which provides a certain amount of efficiency for the machine but little or no efficiency for the analyst himself. The scarce resource in all studies was the time of the qualified analysts, and it would seem appropriate to organize resources to keep these key people usefully busy rather than have them spend a great deal of time on mechanical functions.



Finding 7

Further observations relating to the analyst-study interface were that there is little, clearly identified slack time. Our observations were that, although the number of systems analysis organizations with the AMC is growing, the capability for systems analysis is still a scarce resource. Consequently, there are significant demands placed on existing in-house organizations. These demands are of two types: First, there is a heavy demand to perform or participate in a large number of studies. Secondly, the time period allowed for preparation of any particular study is very short. This leads to the use of those analytical approaches which have most recently been employed locally and are immediately available to them. Unfortunately, this constrains innovation in methodology. Consequently, some period of time might beneficially be set aside for devotion strictly to innovation in methodology.

A further point is that the methodology is not tied to the study funding decision. Consequently, there is little attention paid to the level of analysis which is most efficient for the problem at hand. The rule of thumb which appears to be used is to use the most recently developed technique that the analyst knows, with a slight improvement. Rarely are radical alternatives considered.

This lack of free time for innovation, therefore, is felt not to be the fault of the analyst but the fault of the system which does not present opportunity or incentive to make efficient time allocation decisions.





### Finding 8

With respect to the interface between the analyst and the stock of experience from previously constructed models and collected data, we found that the analysts were often not familiar with the work that had been done in other groups, and this resulted in a considerable amount of effort to construct submodels which were already in existence. There did not seem to be any organized flow of information or any central clearing house to act as a focal point for methodology, or data basis models, or computer technology.

Each study represents a considerable investment not only in funding, but in the development of new data and in the employment of scarce talent. It was a rare instance that we found a study which used or employed significant portions of another study. This did, of course, occur but not to the extent that might be possible if greater emphasis were placed on this approach. Not only were studies rarely drawing upon resources already developed in other studies, but there appeared to be few mechanisms within the AMC study activity which were specifically directed toward the achievement of transferability. In particular, there were no universally known repositories of data on either cost, performance, or methodology. Further, there were few computer tie-ups between system analysis organizations which would enable them to experiment freely with each other's system models without the high cost of travelling back and forth physically for this purpose. Further, there were no provisions within the AMC for updating models with respect



to new technological forecasts, new threat forecasts, new cost data, and other factors. Yet, it was clear that some of these models, particularly the weapon class models, such as Reval Wheels, SAWS, etc., had significant potential for later application.



## Recommendations

In this section, we will present some recommendations which we believe appropriate in light of the findings just presented.

### Recommendation 1

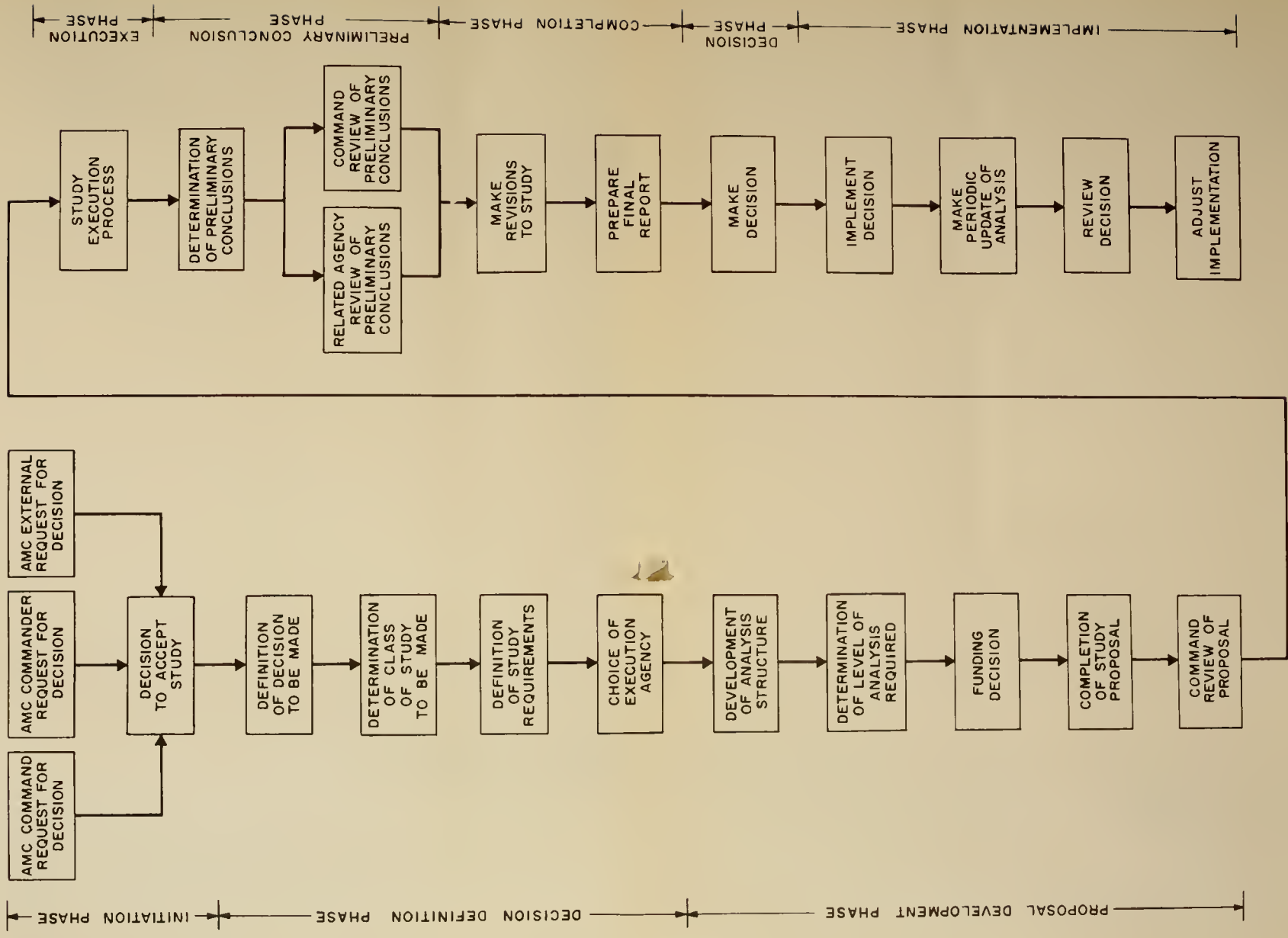
Our first recommendation is that the present study process should be somewhat modified. The current study generation process is described in Figure 1. While there are numerous exceptions to this chart, it depicts fairly well the decision points in the study process. Figure 2 is an alternative approach to this process in which we have tried to make some changes based on our findings.

The first suggested change deals with the interface between the decision maker and the analyst. It is recommended that a decision definition phase be created in which greater attention is paid to the particular decisions which must be made and to the type of study which is most relevant to the decision at hand. We have distinguished two types of activities in this phase; first, the definition of the decision to be made and second, the definition of the study requirements. At present, it is our impression that these two are subsumed in an activity called development of study objectives which, perhaps, is inadequate by itself.

The second recommended change, which also affects the decision-maker analyst interface is increasing the importance of early participation by the decision maker in the study process. We have reduced the importance of his participation at the end of the study and emphasized his participation in the "command review" of the proposal and in the "evaluation of the



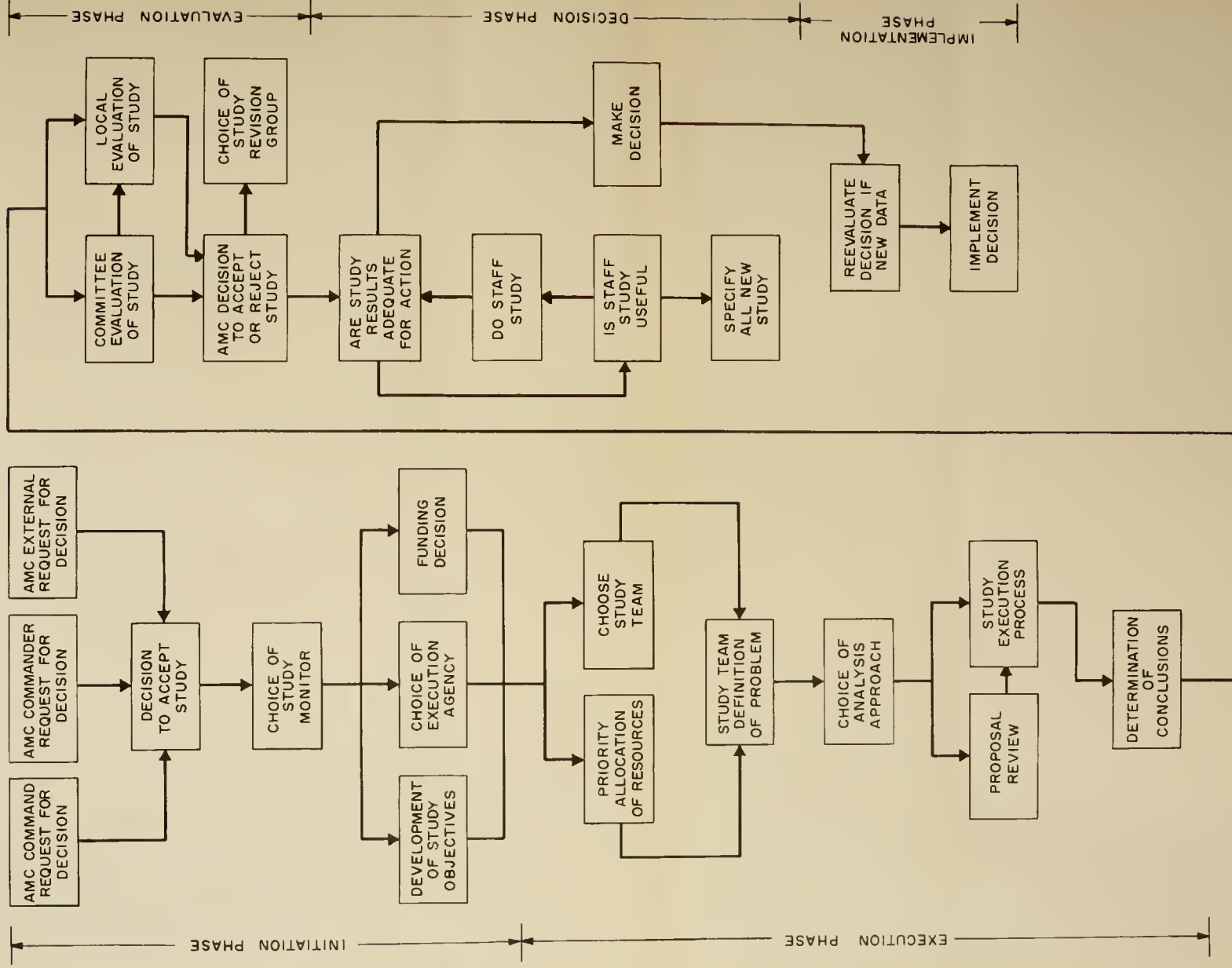
# AN ALTERNATE STUDY GENERATION PROCESS







# CURRENT STUDY GENERATION PROCESS





preliminary conclusions". Each of these reviews should facilitate the incorporation of his views and value judgements at points in the study process where they can be more effectively and efficiently accommodated.

The third change, having impact on the analyst-study interface, is in the procedure for determining the level of analysis and funding appropriate to the study. Under the current system, there is no objective determination of the funding level appropriate to each study. Rather, due to the shortage of time and the failure to explicitly recognize these as important decisions, the level of analysis and the funding decision are determined solely on the basis of the availability of resources and the level of funding used on the most recent study of a similar nature. We believe that funding decisions should be specifically geared to the level of the necessary analysis. To achieve this, consideration might be given to providing study funds for a study by providing annual blocks of funds to the study organizations which is the approach used frequently now. Block grants have their place, but their place is not in the conduct of individual studies but rather in the undertaking of central activities such as methodology improvement, data storage, and other functions to be discussed shortly.

The final change relating to the analyst-study and data bank interface appears in the implementation phase, in which it is explicitly recognized in the "alternative system", that studies have application beyond the point of initial decision. They, therefore, must be stored and updated and re-evaluated so that they are suitable for use in later decisions and in implementation



adjustment programs. These particular changes, we believe, will help significantly in making the study responsive to the decision maker's needs and in reducing their cost and complexity.

## Recommendation 2

### Introduction

A basic premise of formal models as part of the decision making process is the notion that the combination of the model and the decision maker is more powerful than either technique alone. Decision makers unaided by formal analysis and rigorous consistent data evaluation are unlikely to be as effective as they could be with a solid underpinning of fact, as well as assumption and implication testing. Similarly, we have yet to build formal models which are capable of making intelligent decisions without the considerable assistance of managerial talent. The design goal, then, is to mix both resources, the manager, and the formal models in proportions such that we can employ the relative advantages of each. The decision maker can provide his judgement, his ability to structure unorganized material, and his considerable ability in recognizing patterns and drawing on previous experience. The machine and the formal models, on the other hand, have considerable computation ability. They exhibit a great deal more consistency than the human decision maker and are able to draw on the vast data base, collecting detailed facts which are unavailable to the normal human. This mix of skills has been discussed in the planning and control literature in some depth, and we would assert that the technology has finally got to the point where such combinations are economically feasible and have considerable impact on complex decision processes.



Research in complex industrial decision making has shown that such man-machine combinations have a considerable impact on the decision processes of higher level managers. In summary, this impact could be described under five headings:

1) Time. The time actually spent in the decision process, and the elapsed time between the starting of the problem solving process and the final solution is considerably reduced with the use of such an interactive man-machine system. In the experiments conducted to date, an order of ten to one reduction in both decision making and elapsed time has been exhibited. This time is not only significant itself, but it also permits a different form of decision making to be used. It allows the decision maker to move from a serial process with considerable interruptions for implication testing to an interactive parallel process of solving problems.

2) Alternative Testing. This parallel form of decision making allows the manager to test alternatives and see their implications over time. That is, he can ask "what if" questions, and the system can execute their implications and provide him with output variables that show the change in his solution.

3) Several Solutions. This testing of various alternatives results in the decision making having more viable solutions from which to make his final choice. That is, having tested a number of alternatives, he can begin to develop a feel for the magnitude and dynamics of the system and can then use his creativity and vast experience to identify other, perhaps better, solutions.





4) Criteria Development. As a result of this interaction with the model and its structure, the decision maker begins to develop some criteria that enable him to understand the interactions among this system more clearly. This basic systems comprehension not only improves his understanding of likely alternatives, but also gives him a mechanism that forces some rigor and consistency into his decision process.

These four kinds of impacts, briefly discussed above, are indicative of the sorts of benefits that are possible with the use of the newer technology in the form of interactive display systems. Such systems will not solve all the decision maker - model - analyst interface problems, but will alleviate some of them and more importantly perhaps, provide a mechanism that can lead to iterative improvement over time. The interactive display system provides a mechanism to trace the decision process over time, and, with research effort devoted to analyzing such traces, it becomes possible to formalize the improvement of the decision making process. This latter feature suggests that, in the long term, it will be feasible to use such traces as raw data from which we can develop an understanding of the patterns inherent in a decision process. Given an understanding, it may then be possible to develop heuristics which will allow the machine to become an active member in the problem solving process.

As a first step toward such an ultimate solution, we would recommend that research be started with a view to developing a problem presentation package on an interactive terminal. That is, it would be desirable to present to the decision maker the results of the cost-effectiveness study on the interactive terminal. This would not only allow the use of dynamic displays, where the



decision maker could see variables interacting over time, but would also allow the use of graphical presentation and other more creative forms of communication. In addition, of course, the crucial aspect of the display would be to allow the manager to request data and results presentations in the way that appeals to him for a particular decision. Given a particular context and his understanding of the decision that has to be made, he could use his own judgement to view the results and to choose which variables are to be contrasted, and in what sequence. This essentially allows the problem finding process and the model testing process to be under the control of the decision maker involved.

Similarly, it would be possible for the decision maker to test parameters and make changes in the model structure through the use of such a terminal. He would then have quick response to many of the changes he would request, and this would lead him on an interactive path through the assumptions and structure of the model. In such a way, in a one or two-hour working session, he could develop a precise feel for the power and limitations of the model involved. This would in turn allow him to base his decision on a much higher level understanding of the model than he currently has.

This interactive capability not only permits him to look at the results of the model in a dynamic and flexible fashion, but also to test for himself the sensitivity of the model and make the kind of changes he feels are relevant, given the decision that he is faced with, and his understanding of the political environment.



### Recommendation 3

As a further improvement of the decision-maker study interface, it is our recommendation that a minimum set of standard elements be selected and required for each study. As pointed out earlier, to conserve the time expended by the decision maker, some standardization in the report format is necessary. The standard elements listed in the findings might be an appropriate minimum set. Some of these elements we did not find in the studies we examined; for example, source of the data, cost of the study, original plan time and actual time to perform the study. However, these we believe are essential for accurate evaluation of the study process and will have beneficial effects beyond a simple transfer of information to the decision maker.

### Recommendation 4

The next two recommendations deal with the interface between the analyst and the store of existing knowledge.

In the findings, we identified the importance of increasing the transferability of the benefits associated with the studies. To achieve this, we recommend the creation of an organization which will be responsible for insuring and achieving this transferability. Specifically, it will perform the following functions.

- 1) It will co-ordinate the data bank activities and insure that at some known point within AMC the latest data for each weapon and environmental condition are kept and updated.



- 2) It will co-ordinate a model bank and insure that those models which have later relevance are kept up to date as new data is supplied to the data bank.
- 3) It will insure that methodological improvement programs are undertaken by each study group and will be responsible for the approval and funding of methodological improvement programs.
- 4) This group will be responsible for co-ordinating the AMC and CDC study activities.

This is not a recommendation to establish a centralized data bank and a centralized model storage facility which will perform all the methodology improvement programs itself. The importance of decentralization seems evident by virtue of the fact that specialized expertise exists in many of the agencies. It is clear that air defense expertise is presently at Huntsville, that artillery expertise is presently at BRL, that mobility expertise is presently at the Tank Command and in other places. However, with this level of expertise so spread around geographically it is important to have a group which provides certain central co-ordinating functions to these multiple activities. In particular, this central group should set standards for reports, model structure, data format, presentation, etc. It should audit the data bank activities, the model storage activities, and methodology improvement activities at each of the study centers. It should allocate funding to each of these study centers in accordance with their needs for data bank maintenance, model storage maintenance and methodological





improvement. Finally, it should serve as a central point or contact to which all persons may go when desiring information about the existence of data models, methodology, or other points of interest within the AMC study system. At present, there appears to be a considerable lack of understanding of the capabilities which are existent throughout the system. While this information is understood at the central headquarters level, it is not well understood within the study analysis groups. We have suggested, therefore, the centralization of certain control activities, but the maintenance of the decentralization of the major operational activities. In short, we are suggesting an information retrieval facility where the analyst can inquire on a remote basis about the characteristics of data available in a central data bank or the characteristics of models available in a central model bank. Such a file, of course, could also be used by decision makers or decision-maker staff in deciding the funds and time necessary to make a study on a particular system. In fact, such a central bank could also have presentation devices and software packages to allow the dynamic presentation of material to decision makers. In any event, the costs and conceptual effort involved in creation of such a facility is relatively small in light of the benefits this would provide, and the reduction in time and analyst effort needed for these complex studies.

#### Recommendation 5

In order to achieve the kinds of control and transferability of benefits cited earlier, certain kinds of standardization will be necessary. One will be a standardization of the classes of models. For example:



- (1) There are parametric analyses for the purpose of establishing optimal weapon designs.
- (2) There are utility evaluation studies for the comparison of one weapon approach against another.
- (3) There are class analysis studies for the purpose of evaluating entire classes of weapons such as small arms, trucks, etc.
- (4) There are product improvement studies for evaluating modifications to existing weapons.
- (5) There are requirements analyses for evaluating the environment in order to specify the optimal weapon.
- (6) There are effectiveness studies for simply analyzing the effectiveness of a weapon.
- (7) There are cost-effectiveness studies for evaluating cost with respect to effectiveness.
- (8) There are research program studies for identifying areas of high technical potential in which R&D funds should be concentrated.

Another form of classification is by model structure. Presently, models are categorized by end use, i.e., truck models, tank models, artillery models, air defense models, etc. It might be desirable to classify the sub-elements of these models, since many of the sub-elements in end use models have similar characteristics. Submodels might include terrain, communication, mobility, target acquisition, etc. The classification of these submodels and their mapping into end use models should be undertaken by the AMC so that areas of strength and weakness can be found in the overall system of models.

We feel that resources should be provided to structure the technical aspects of the model building process to take advantage of developments in technology and concepts. The organization needs to allocate resources to



to the problem of maintaining a central communication facility that will allow technical analysts to draw on the work that has gone on before, and also to provide them with some perspective or overall policy direction in regard to model structure. In its simplest form, this might be a decision to use a common computer throughout all of the study processes, or at least to use a standard higher level language. There could be some guidelines developed along the lines of the following methodology section in this paper and there could be some central software development to support the decision-maker interaction that is required. The resources might be put first to the problem of providing the decision maker with a flexible interface to the model, or they might be spent on the problem of providing analysts with a flexible interface to the model. In either event, such effort is likely to be highly rewarding in terms of improvement to the process. Provision of such support for the analyst is likely to result in a very considerable drop in the elapsed time for the model creation activity.

### Conclusions

Each of these five recommendations has at its heart the attempt to improve the interface problems inherent in the four groups identified in Figure 1 above. One way of improving the problem, of course, is merely to recognize it and to begin to work on possible solutions. However, it is also true that technology has improved enough in recent years that interactive display terminals tied to some central computing facility over regular telephone lines is a technically feasible and economically desirable possibility. To exploit such techniques requires some effort on the part of



the organization concerned. It is not possible to take previous research projects or software packages and apply them as is to the problems that the cost-effectiveness studies in the AMC environment have. In that sense these techniques are only a mechanism to force a rigorous consistent evaluation of the role of cost-effectiveness in the decision process in AMC. However, our industrial experience indicates that this sort of effort is well worthwhile, and the technology, although only a means to an end, provides some very tangible and immediate benefits to all concerned. Formal models have considerable power and potential, but only in the hands of the decision makers who are eventually charged with the responsibility of making the final decisions. Accomplishing this task calls for a considerable degree of effort and creativity on the part of the organization involved, and it is clear from our study of the cases made available to us that there is a great deal of potential yet to be realized in the present cost-effectiveness study process.





## VII. Findings and Recommendations

### (B) Model Methodology

#### Introduction

The AMC is responsible for the selection, development, and procurement of materiel that will best satisfy the projected requirements of the Army, within specified resource constraints. In addition, AMC is expected to provide information inputs to higher level agencies (i.e. Department of the Army and the Department of Defense) for making decisions on alternative weapons systems, and on the mix of systems appropriate for implementing defense strategies.

Both these roles involve extensive use of a group of formal techniques variously labeled "systems analysis", "cost-effectiveness analysis", etc. We shall use the term systems analysis (SA) to refer to these formal models. The need to use SA mainly stems from four sources.

- (a) The limited capacity of human beings as information processors or decision makers. Evidence suggests that the unaided human cannot effectively cope with more than a few, perhaps five or ten variables, in any decision situation. Systems analysis provides a framework for processing, evaluating and condensing available data so that the decision maker can use the output of such models as an input to his decisions.
- (b) The complexity and rapid rate of change of technology demands that many variables (often hundreds) be taken into account in any materiel decision, effectively precluding the use of "pure" judgement or intuition in such situations.



(c) The need to allocate limited resources to the development and procurement of materiel implies the need to develop measures of costs and effectiveness of alternative systems in the context of Army objectives, potential or actual enemy capabilities, and the current or future state of technology. Such measures clearly require formal SA techniques.

(d) Finally the need for some type of mental discipline to state explicitly all the critical cause and effect relationships and also methodically search for and evaluate alternatives.

As a result of the above needs, SA has evolved to produce measures of the costs and effectiveness of weapons systems, usually in the context of providing guidance to decision makers required to choose among alternative systems for design, development, or procurement.

Although the aspects of cost and effectiveness are not independent, yet our examination will consider only the problem of developing effectiveness measures for models.

As a broad generalization, SA studies can be described as "transformations" that accept as a basic input the physical characteristics (blueprint specifications) of a weapons system and produce as output a measure of the system's effectiveness. To support this transformation, additional inputs describing the environment in which the system is to be utilized, the capabilities and strategies of both friendly and enemy forces, and the subjective valuation of battle outcomes, are required. Such a transformation process, in the present methodology, is usually monolithic. This means that a single study,



often created ad hoc to deal with a single weapons system, contains the entire transformation and attempts to provide a single measure of effectiveness. The parts of these studies are so interdependent (because of the monolithic structure) that the transferability of results is limited extensively, and very little of a study can be salvaged if for some reason changes to the underlying assumptions must be made. Unweildy structures also impose a barrier between the user and the model, because the decision maker cannot effectively interact with and benefit from the study. As we have already pointed out, unless the decision maker feels comfortable with a model, he cannot successfully integrate it into his planning activities. He may use the models either because of faith or because of hesitancy to admit ignorance. This is, of course, somewhat an exaggeration of the facts, but we shall proceed to examine problems that arise from the degree to which this monolithic type of study effort is prevalent.

### Findings

The shortcomings of the methodology described above are reflected in several classes of symptoms identified in the course of our study. They are also common in most applications of formal models in industry as well as government.

Changes in the assumptions, environmental factors, objectives, and other data inputs to a SA study, frequently invalidate the study conclusions and require that an extensive new analysis be undertaken. This we found to be a common occurrence. Such changes are commonplace results of rapidly changing technology, reformulation of strategic and tactical doctrine,



shifting assessment of enemy capabilities and intentions, and, to a limited extent, advances in SA techniques or results of newer related studies. In short, these changes are a result of the same underlying circumstances that led to the use of SA. Before the advent of SA studies the decision maker could not cope with the many variables and the changes which were occurring in such variables. We envision the day, if we are not already there, when the user of studies will be unable to cope with the vast inventory of specialized studies. If we are to save time and financial resources we must find common elements in SA studies and impose some type of standardization scheme on the basis of these common elements.

A second class of symptoms that we observed and which relate to the ad hoc monolithic character of SA studies consists of excessive study complexity and the long lead times required to complete the studies. The former precludes effective decision-maker interaction with the study, since he cannot expend the time necessary to adequately explore study assumptions, techniques and results. The latter discourages the utilization of SA to make decisions, due to the excessive time and expense involved. Both complexity and long lead times reduce the ability to improve on previous results, since the results are not easily understood and may be out of date in any case.

Third, important value judgements are being implicitly made by analysts in order to complete the transformation process. Such value judgements should be left, where possible, to the decision maker who is presumably more capable of applying the required broader context (including relevant non-quantifiable data), than the analyst.





These symptoms can be related to the broader problem of providing effective feedback in the decision-maker-analyst interface, in order to promote learning from experience. Such learning is a key element in improving the value and utilization of SA effort. In order to provide feedback, a proposed methodology should help provide the following specific capabilities:

- (a) Creation of motivation to act on differences between desired and actual study effectiveness, by allowing identification of responsibility for errors and areas where model improvement is necessary.
- (b) Reduction of lead times for the study process to provide timely feedback before large commitments of resources are made.
- (c) Means which will enable the decision maker and the analyst to more fully explore the characteristics and sensitivity of model results to particular assumptions or data values.
- (d) Greater consistency in data inputs, models and assumptions among different studies, to help pinpoint areas for improvement.
- (e) Capability to salvage parts of a study in order to save time and resources, and at the same time encourage transferability of useful results.



### Recommendations

In order to achieve the above goals, we propose that some AMC effort be directed toward evolving the modular, "building-block" approach as described here.

To structure the SA process and achieve the goals described above, we first break down the transformation process for a single weapons system into four stages, identifying the inputs and outputs at each stage. This structure is shown in Figure 3.

There are several important features of such a structure. First, we are implying parameterization of the input and output variables at each stage in the transformation process for a class of systems meeting similar program capability objectives, or having similar physical or performance characteristics. If, in fact, the weapon systems were similar, the number of distinct models required to generate effectiveness measures could, ideally, be reduced to the four stages in the process. Because weapon systems are dissimilar, we anticipate a situation like that shown in Figure 4.

For a given class of systems, several distinct models would be required at the first stage due to the lack of comparability (equivalent parameter sets) for different systems. As the higher stages in the process are reached, the number of distinct models needed should be reduced, as each lower-stage model has as its output a more clearly standardized set of parameters.



Figure 3: Multi-Stage Transformation Process

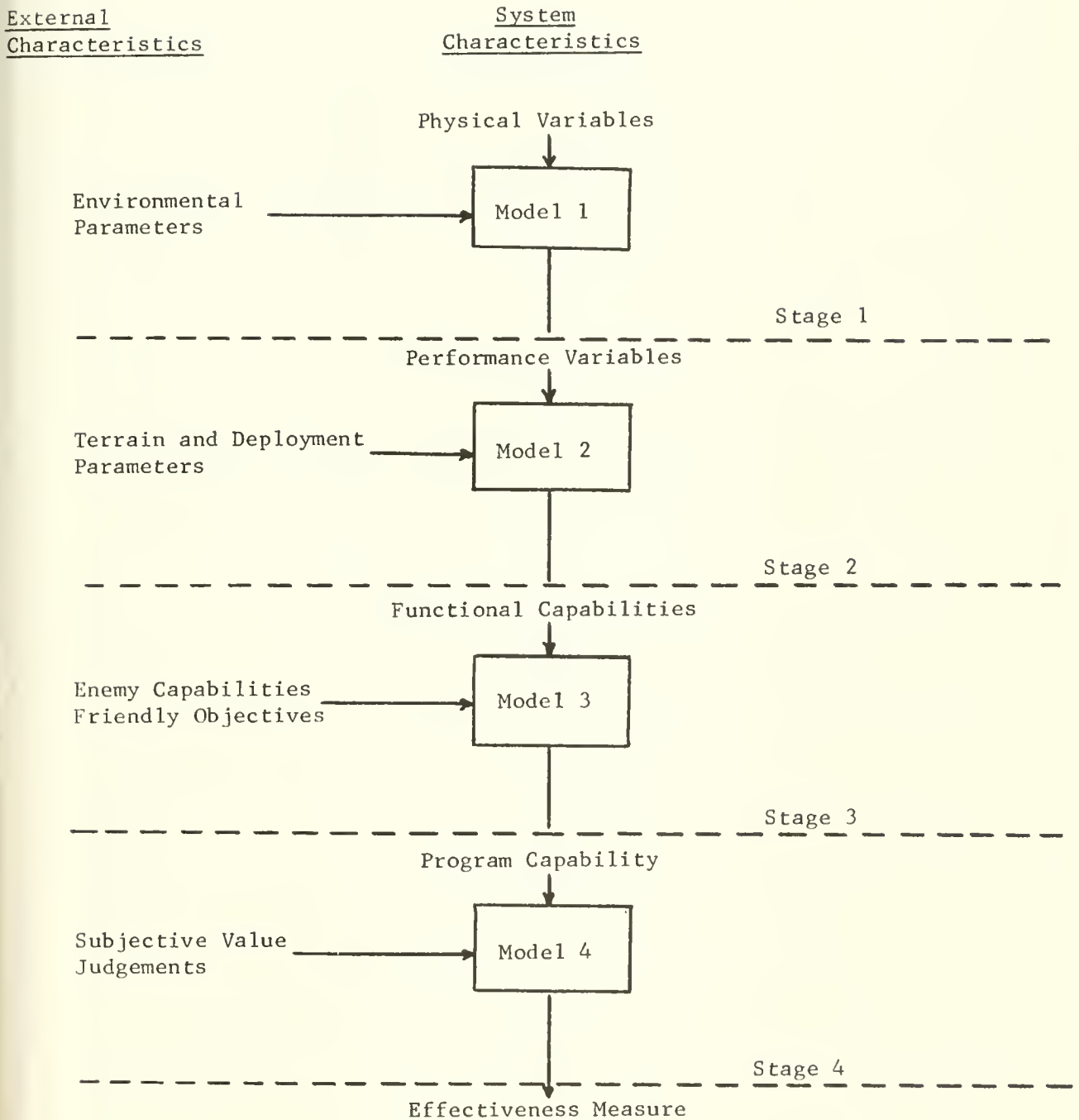
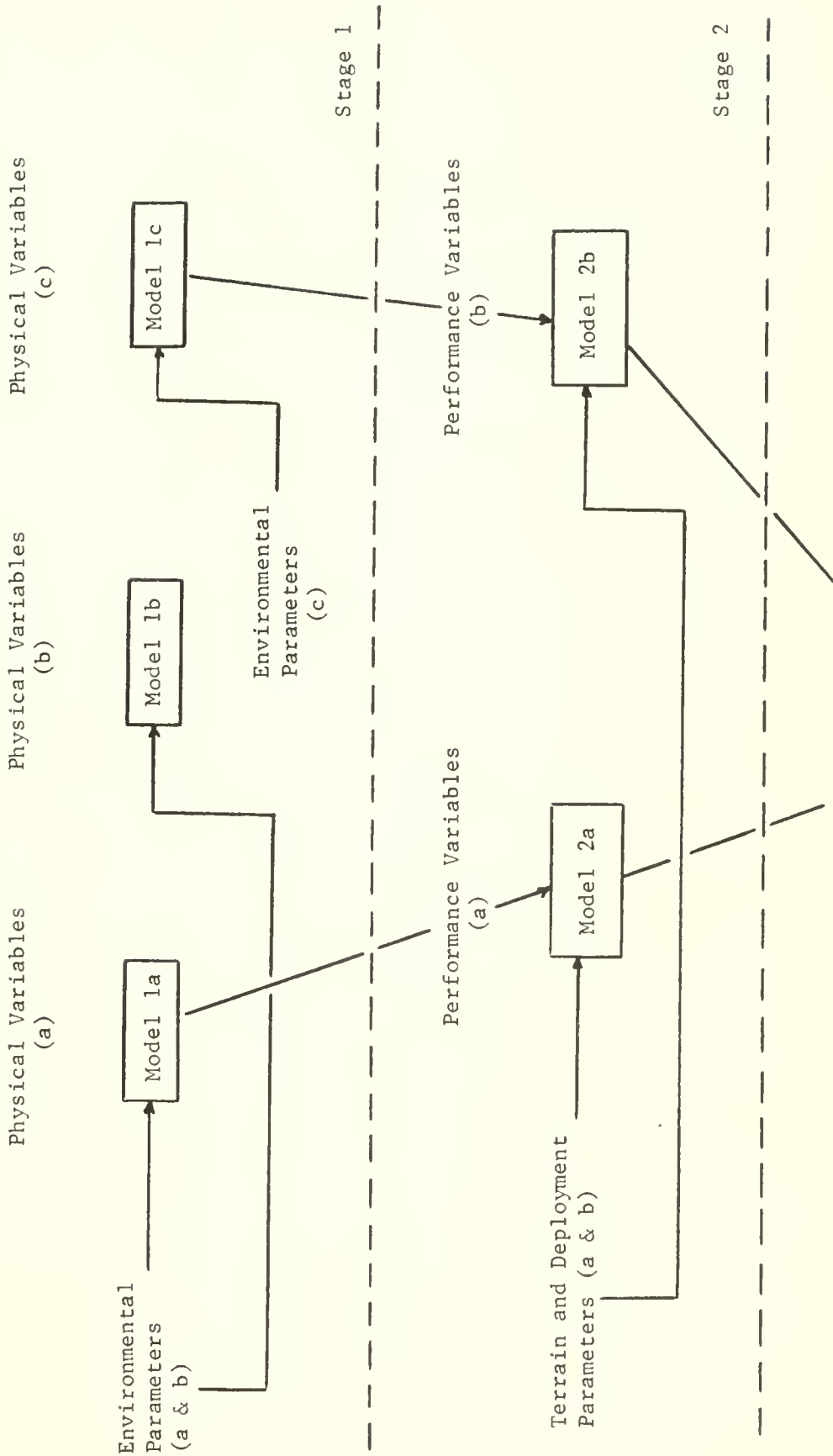




Figure 4: Models Needed for a Class of Weapon Systems

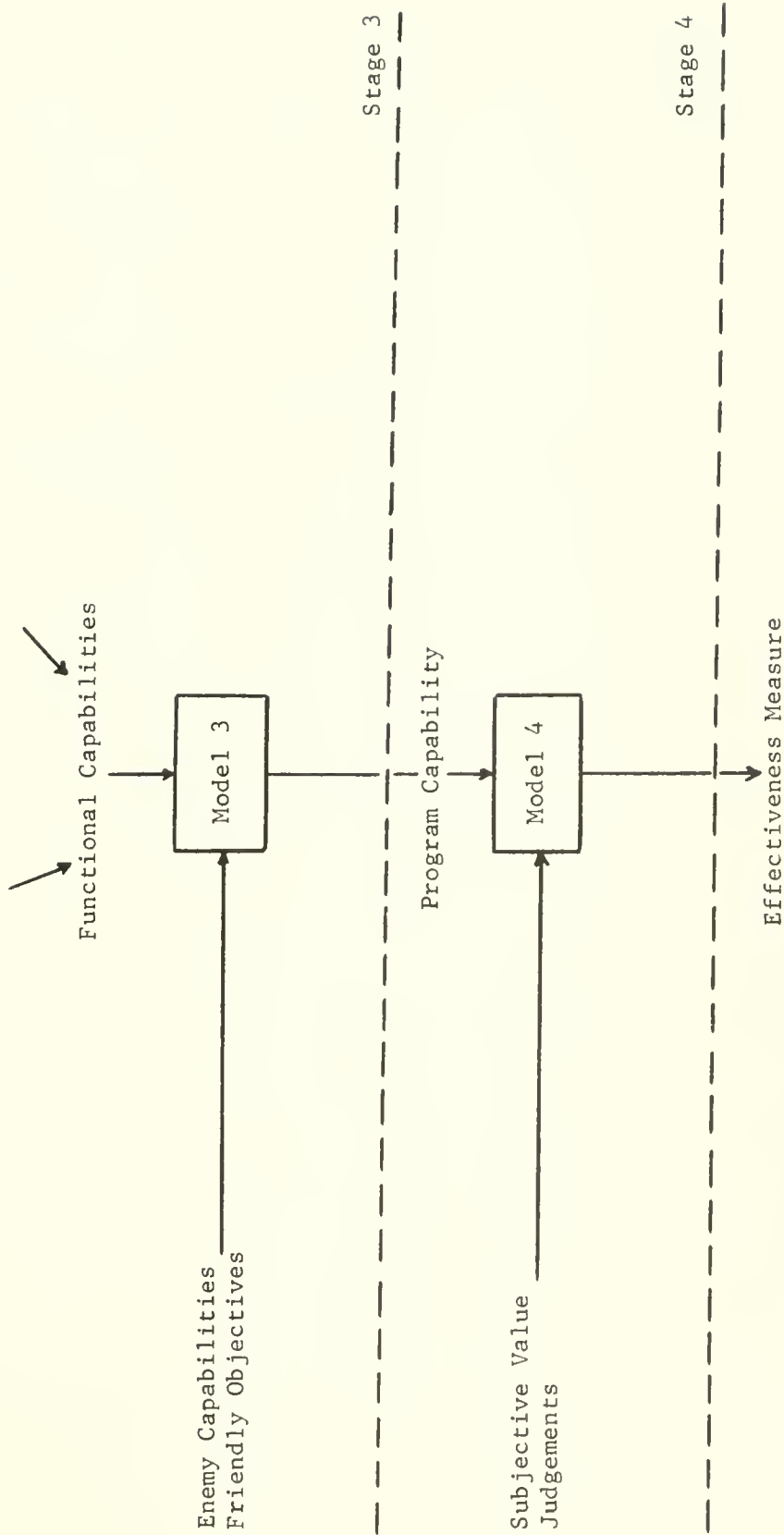


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Figure 4 (continued)





In order to provide a concrete illustration of this structure, we have examined the mortar study ("Effectiveness Comparison of M329A1 vs. XM571 (RAC) Mortar Shells", BRL). The parameters and variables involved at each stage in the transformation process of the mortar study are shown in Figure 5.

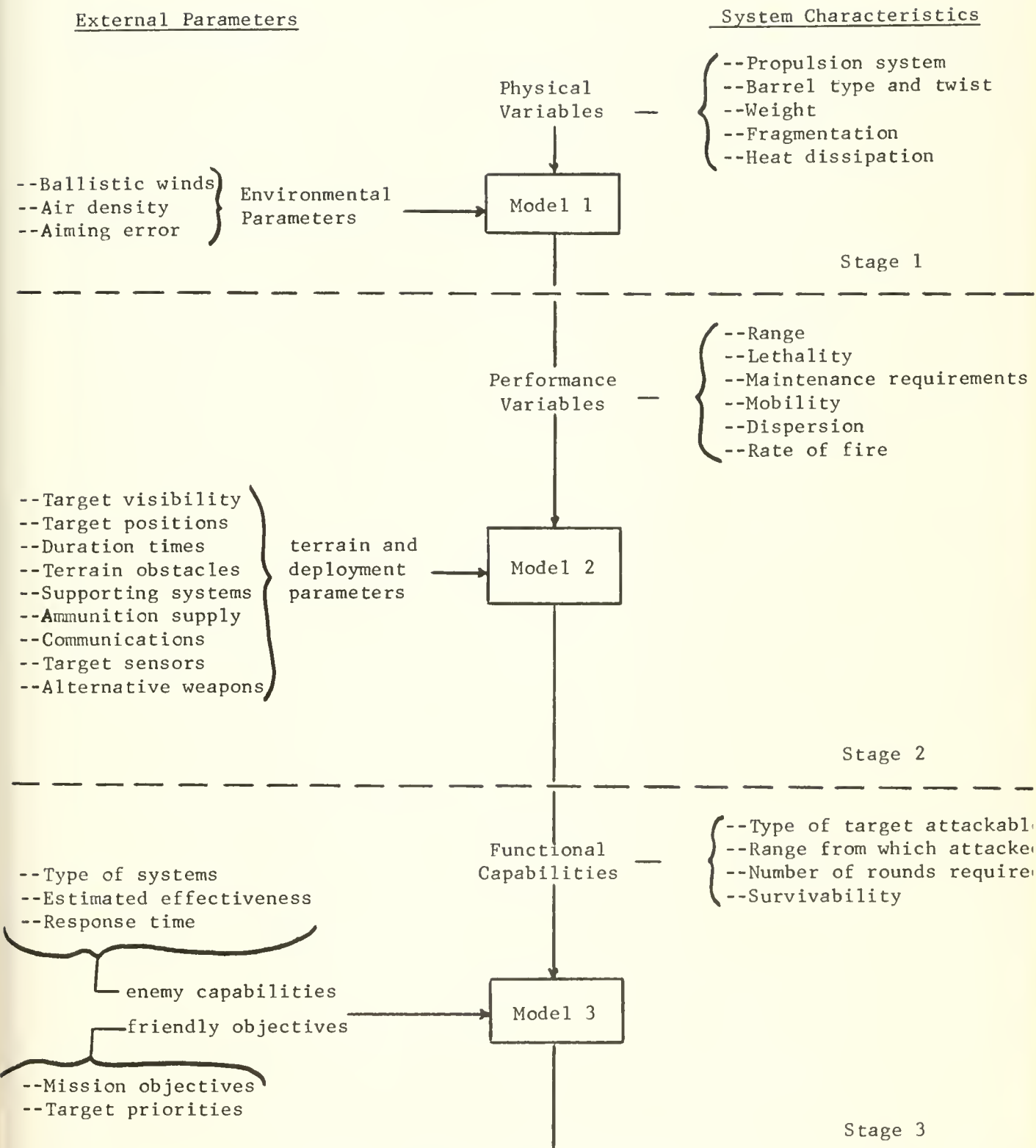
At this point, we shall attempt to clarify the terms we have been using to describe the model structure. We first distinguish between external parameters, which describe the tactical and physical environment within which the weapon system is to operate; and system characteristics, which describe the attributes of the weapon system itself.

Within the category of system characteristics, we have physical variables, performance variables, functional capabilities, and program capability. Physical variables represent the design of the system; they are the basic characteristics that are expressed in the blueprint specifications. Performance variables describe what the weapon can do by itself, in a neutral, non-hostile environment. These would be similar to field testing data. Functional capabilities describe the weapon system as it would perform in a battle environment; terrain, target and supporting systems must therefore be considered. Program capability describes the results of a mix of weapons systems and strategies; it thus places the individual weapon in a broader strategic context, incorporating enemy capabilities, and our own specific military objectives with the level of effort (# of systems) as a variable.

As can be seen from an examination of the parameters and variables involved, in Figure 5 a very nearly equivalent set of models could be used to evaluate the effectiveness of any ground-based weapon system firing projectile(s) at enemy targets. At worst, we would anticipate changes in



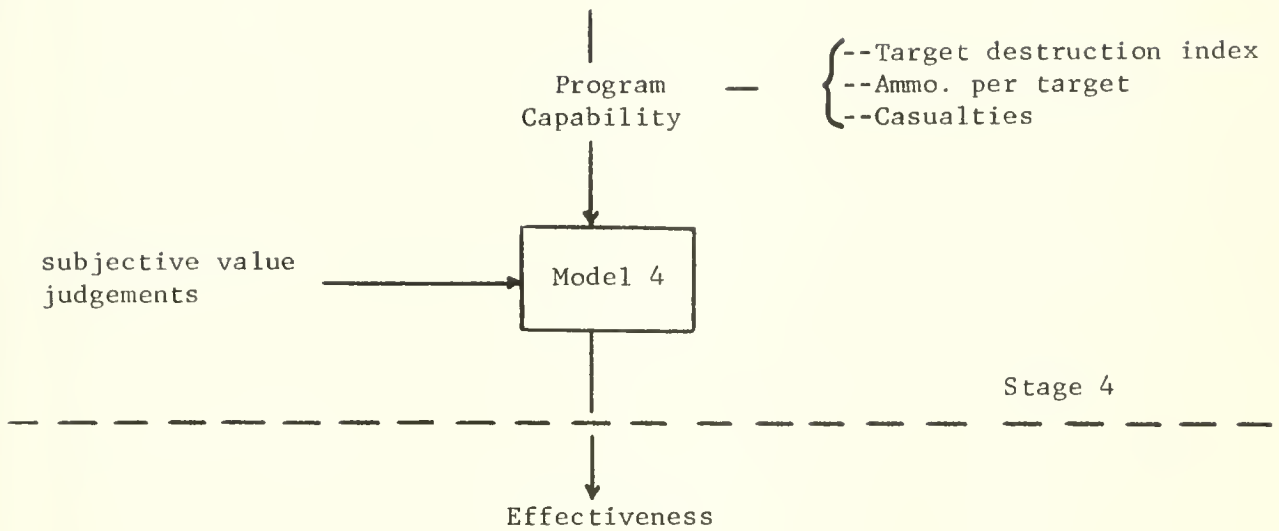
Figure 5: Mortar Study Model Structure



continued on following page



Figure 5 (continued)







model 1 to handle somewhat different specifications, but the set of performance variables required as input to model 2 should be quite similar.

We must now examine the usefulness of such a structure in the light of the required capabilities outlined under "Findings". First, such a structure will enable closer focus on problem areas in the methodology, because a model will be used repetitively. This should result in the detection of errors and enable incremental improvement to be made for each model. Second, lead times should be greatly reduced because studies could use existing models "off the shelf". Third, the extensive parameterization will allow the testing of the sensitivity characteristics of each model with respect to two types of input variables, input from lower-stage models, and parameters describing assumptions about the external environment within which systems will function. Fourth, greater consistency is achieved directly through repetitive use of the same models, forcing the analyst to carefully define and classify data for the relevant set of variables and parameters. Finally, a data base for models can be built which will allow fast access to the existing inventory. The latter will be classified on the basis of the various model stages and by relevant characteristics (external-environmental and internal-system characteristics). Such a classification scheme will be very useful when the link between models and on-going information systems is established. For then, we will be able to integrate parts of studies and also develop schemes for updating the data base automatically with each new entry.



### Implementation Considerations

We now consider the steps necessary to implement the re-structuring of SA efforts described above. First, existing SA studies should be examined in the same way as the mortar study example, to determine the required sets of standardized variables and parameters. A sufficiently broad range of studies is required to insure that the resulting specification of model structure is relatively complete. Also it will be necessary to go through an extensive examination of existing studies to justify the choice of parameter sets. The range of studies should include systems with functional capability in the areas of sustenance, transportation, communication, target engagement, and intelligence. Due to the lack of consistency in presentation of study results, to which we addressed ourselves before, the amount of time required to isolate the relevant variables and parameters is likely to be large. Second, a system for standardization of input data (both external-environmental and internal-system) must be developed and standardized formats for the collection, use, storage and update be specified. These formats should take into account the classification of variable and parameter sets evolved above, as well as the form and availability of the data.

Third, the data base to be utilized for model input should be organized along the modular, hierarchical lines proposed earlier. This will facilitate updating of the data in response to changes in the environment, and re-structuring of such to fit new models as they evolve.

Finally, a program to provide continuous evaluation and feedback of model validity and utility should be established. As other sections of this report suggest, such a program will require meaningful participation on the part of both the decision maker and the analyst.



### VIII. Possible Paths for Future Research

The activities that we carried out last year and our exposure to various agencies, people and studies, suggest a number of useful research possibilities for the future. These can be explored, no doubt, by agencies within the Army. However, the day-to-day pressures from the operating environment and the history of institutional settings serve as an impediment to the successful pursuit of some of these activities that we identify here, if these are carried out internally. We believe that a joint effort by the Army and our research team will be very productive, and, for this reason, we are ready to undertake a continuation of this research for another year and concentrate on some of the topics listed below.

The order in which these projects are listed reflects our notions of priorities. Bearing heavily on our judgement were such practical issues as the utility to the Army and the feasibility of researching the topic at some satisfactory depth within a year. We do not, of course, propose to attack all these topics during the next twelve months. The amount of effort required for such a task far exceeds our available resources. Only parts A and B might therefore be contemplated for next year.

#### A. A Conference to Interface Decision Makers and Systems Analysts

In the course of conducting our research, we were impressed by the general availability of talent within the organizations which perform studies for the Army. It is also clear, however, that the work setting is not conducive to meaningful exchange and cross fertilization of ideas among representatives



of different groups involved in cost-effectiveness analyses. The Review Board setting is not intended to provide the medium for improving study methodology and analyzing the problems facing decision makers and systems analysts.

For the above reasons, we believe that it would be fruitful to invite to MIT, the decision makers, the directors of major analysis organizations and the proponents of various methodological approaches and exchange ideas for the improvement of studies and of the overall study process.

In order that such a conference be effective, position papers on critical problems must be prepared and circulated ahead of time. The conference itself will be devoted to discussion on the papers and to the summarization of findings. The papers, discussion, comments and integrative remarks could then be put together for wider distribution.

#### B. Develop Methods for Building Flexible Models

Our research, so far, convinced us that managerial decisions within AMC and the Army are very sensitive to quantitative models. The opposite, however, is not always true. Because of weak interfaces between the decision makers and (a) the systems analysts, (b) the models, and (c) the data bases, we find that there is an urgent need to improve the sensitivity of the models to the needs of the decision maker. One part of such effort involves improvements in model methodology.

In another part of this report we suggested a "building-block" concept for structuring cost-effectiveness studies. The purpose of that suggestion was to create flexibility, reduce the time required for completion of a study, and encourage updating and transferability of the results of studies.





We are happy to note that ATARS is using one such approach. Furthermore, the techniques developed for input-output analysis (matrix approach) offer some promise. No doubt there are other techniques which use the principles of transformation, decomposition (modularity), and hierarchical structures which merit attention. For these reasons we believe that further research is required for the development of the necessary theory and methodology for guiding the activities of AMC study agencies.

We propose to work closely with the agencies performing cost-effectiveness analyses in the development of the "building block" and "matrix" approaches discussed in our reports. In developing the former concept, we will attempt to identify in conjunction with the AMC personnel, the most logical and suitable points for placing standard transformations and hierarchical breaks in the AMC-wide model structure. We will also attempt to develop the necessary framework for classification of inputs and outputs necessary for the successful use of such models. A logical extension of the "building block" approach will be an application of some of the concepts of input-output analysis to identify the relationships between Army objectives and various weapon systems, and between the weapon system submodels and the complete weapon systems.

The results that we envision emanating from such a capability, as described above, are: reduction of the length of the study process, faster response, reduction of the frequency and cost of revisions, learning through information transfer, and evolution of a classification framework which will pave the way for projects "C" and "D" as described here.



C. Develop Classification Schemes for Studies and Construct Efficient Data Bases

Transferability of results is a must, if learning from the experience of others is to take place. To unlock the tremendous power which now remains mostly within the study, a common scheme for classification and updating must evolve as well as a procedure for maintaining a common data base. A research group can work together with decision makers and systems analysts to develop such schemes for classification. From then on, each study shall, among other things, include a page with information pertaining to the adopted classification scheme and across the various dimensions which were chosen for this purpose. This information will be used both for cataloguing the study itself and also updating the common data base.

D. Designing an Information System for Controlling the Study Process, and Linking the Studies with Operations

In our findings we have pointed out some of the advantages of formal planning and of linking formal plans and operations through managerial information and control systems. A very useful project for the Army Materiel Command will be to undertake the development of such an information and control system. Its objectives should be to develop and implement procedures by means of which replanning will become an integral part of the continuous control process. The replanning and control that we have in mind, involves both that which is a part of the study process and the activities which are initiated as a result of the implementation of the recommendation of studies.

The development of such an information and control system (to obtain meaningful feedback from the point of initiation of a study to the point of expiration of its final consequence) will involve extensive investment over a period of at least three years.



#### E. Simulation of Different Approaches to Cost-Effectiveness Analysis

Decision makers today must have at their disposal systems which allow interaction. In this way, alternative plans may be tested and knowledge gained on the basis of hypothetical cases. Visual display units with a capability for graphical presentation of results are available and in current use so the Army must now start planning for the future. These devices provide an effective interface between the human decision makers, the models, computer technology and data banks.

For such an approach to systems analysis, the efforts of the decision maker, the study preparation agency and MIT must be brought together and applied to one or two studies. If successful, these experiments will enable:

1. The decision maker to develop more effective plans
2. Researchers of the management to gain insights into the planning process and move toward the development of intelligent information systems and
3. Systems analysts to develop standard approaches for different kinds of studies.

#### F. Tests for Sensitivity of Decisions to Model Complexity

The present system generally leaves it up to the analyst to decide how complex the study should be. A research program could be undertaken to evaluate the effect of complexity and model sophistication on the quality of decisions produced by the decision maker. One way to carry out this project is to conduct two parallel programs of different complexity focused on a particular problem or decision. The results of these two programs, prepared independently, could then be evaluated to determine what benefits sophistication offers and what criteria might be used for deciding the level of complexity of a given study.



## Attachments





## Attachment 1

### Study Hypotheses

1. Decision makers expect that the models will make decisions for them rather than helping them to make the decision.
  - a. They do not participate in the directive writing process or in the face-to-face negotiation of project objectives and methodology.
  - b. They do not participate in proposal review.
  - c. They do not participate in analysis review.
2. Variables outside the scope of the cost effectiveness study have a significant impact on a decision. That is, in many cases, events which were not examined in a cost-effectiveness process are found to be governing.
3. The study time before a military systems decision is made is longer than necessary.
  - a. Most studies are re-done to examine conditions not previously specified by the decision maker, either because the decision maker did not take the directive setting process as a significant part of the planning activity, or because there were changes in the environment which were not possible to forecast.
  - b. Most studies which are re-done, are re-done to examine new conditions that were not previously specified. That is, there could have been higher level inputs from senior decision makers which were known if the decision makers involved had been asked to participate in the directive setting process.



4. There is no development program to increase the study capability.
  - a. Ad hoc studies use most of the available study resources, which leaves little or no time for basic research in study methodology.
  - b. Studies tend to be treated as unique rather than providing an opportunity for making progress toward a greater integrated capability, or increasing the understanding of those involved in that class of model. This is the case because the resources applicable to this generalization and study methodology process are not adequate.
  - c. There is no formal information feedback system for continued improvement of study quality.
5. The assumptions of the study often turned out to be inadequate thus affecting the final decision.
6. These studies are not flexible.
  - a. The models are not built to include a decision-maker model interface.
  - b. Lack of a systems or hardware interface results in a data bank that contains data recorded on the wrong media or in the wrong format. This results in a lot of time and effort being spent in transforming the data or in a new data generation program.
  - c. Models are generally not parameterized.



Attachment 2



Project Manager or Study Manager Questionnaire

Title of Study \_\_\_\_\_

Date \_\_\_\_\_

Source of Data or  
Person Interviewed \_\_\_\_\_

Position \_\_\_\_\_

1. What was the initially estimated cost?

2. What amount of funding was approved?

3. Who made the funding decision?

4. What criteria were used in evaluating the appropriate level of funding for the study? (Agency quote, study priority, magnitude of decision to be made, availability of staff, scope of task, etc.)





- 5 Which major organizational elements within ARL provided personnel, time or information to the study?
- 6 Which Army Commands or other similarly large organizational elements within the Army such as DA Staff provided personnel, time or information to the study?
- 7 How many other military services provided personnel, time or information to the study?
- |                      |                              |
|----------------------|------------------------------|
| _____ Navy           | _____ Office of Sec. of Def. |
| _____ Air Force      | _____ CIA                    |
| _____ Marines        |                              |
| _____ Coast Guard    |                              |
| _____ National Guard |                              |
| _____ Other          |                              |
- 8 What was the leadership approach?
- |  |
|--|
| _____ one director with complete authority |
| _____ a team coordinator                   |
| _____ dual or joint leadership             |
| _____ other _____                          |



9 What were the characteristics of the team leader

\_\_\_\_\_ Civilian \_\_\_\_\_ Military

Rank \_\_\_\_\_

Education Degree \_\_\_\_\_

Fields \_\_\_\_\_

Year received bachelor's degree \_\_\_\_\_

Experience \_\_\_\_\_

12 How many alternative systems were considered \_\_\_\_\_

13 Why were these alternatives selected?

14 Which performance criteria were able to be converted into financial measures?

Which were the measures which could not be converted into financial measures?



15. How many parameters were examined? List if possible

16. How many environmental conditions were examined? List if possible.

17. Was a specific attempt made to relate not commensurate criteria?

\_\_\_\_\_ by ranking

\_\_\_\_\_ by using a figure of merit

\_\_\_\_\_ by setting minimum allowable levels on each separate criteria

\_\_\_\_\_ criteria were left unrelated

\_\_\_\_\_ other \_\_\_\_\_

18. Was a sensitivity analysis made of any of the parameters in the study?

\_\_\_\_\_ how many

Which ones?



19. What per cent of the parameters in the model could be changed so that new cost/benefit rankings could be provided in a week?
20. What data which you did not have would have significantly improved the study?
21. What was the extent and source of data which had been previously collected and recorded?
22. How much time would it take to change a major non-cost assumption of the study and re-evaluate the conclusion?





23 What were the most unsupported assumptions in the analysis?

24 What was the actual time and cost required for conduct of the study?

25 How adequate was the time provided for the conduct of the study?

more than adequate	adequate	a little inadequate	very inadequate
( )	( )	( )	( )

26. Was it possible to answer all the questions in the study directive completely?

\_\_\_\_\_ How many?



27. What was the conclusion of the study?

28. Was one alternative recommended over all the others?



Decision-Maker Questionnaire

Title of Study \_\_\_\_\_

Date \_\_\_\_\_

Source of Data or  
Person interviewed \_\_\_\_\_

Position \_\_\_\_\_

1. Why was the study initiated?
  
  
  
  
  
  
  
  
  
  
2. What magnitude of decision was perceived at this point as being at stake?
  
  
  
  
  
  
  
  
  
  
3. What were the most unsupported assumptions in the analysis?
  
  
  
  
  
  
  
  
  
  
4. Which questions in the study directive or workstatement could not be completely answered?  
  
\_\_\_\_\_ How many?
  
  
  
  
  
  
  
  
  
  
5. How many reviews were made of the validity of the study, by whom?



6. To what extent were the findings of the study surprising or unanticipated in comparison to the expectations of people before the study was made?

very  
surprising |-----| obvious

7. How thorough was this study?

very  
thorough |-----| not  
thorough

8. How good was the methodology?

appropriate |-----| inappropriate

9. How good was the interpretation of the analysis?

very  
good |-----| poor

10. How good was the study in meeting the decision requirements?

very  
good |-----| poor

11. How strong was the recommendation of the study relative to the other considerations in making the decision?

very  
strong |-----| very  
weak





12. What decision was made as a result of the study?

- ☐ Buy
- ☐ Partial or Pilot buy
- ☐ Test
- ☐ Wait
- ☐ Restudy
- ☐ Reduce a program
- ☐ Terminate a program
- ☐ Change a policy
- ☐ Other \_\_\_\_\_

State in greater detail and why was the decision made.

13. What additional information had to be obtained and considered in order to make the decision?

14. Were there political considerations?



15. What was the short run and long run funding magnitude of the decision made?

\$ \_\_\_\_\_

16. Who was the decision maker and what was his rank and position?

17. How high did the study get briefed?

18. To what extent did the decision made agree with the conclusions of the study?

19. What auxiliary studies and decisions were required as a result of the study?

Identify the purpose of each.



20. What were the recommendations of the later studies?

21. To what extent did the decision maker participate in any part of the execution of the study?

22. What actions were taken subsequent to the initial decision? Give dates for each action.



23 To what extent were the assumptions and conclusions of the study borne out in later events?

24 Was the decision later reversed?

\_\_\_\_\_ yes      \_\_\_\_\_ no





Questionnaire for Cognizant Office

Title of Study \_\_\_\_\_

Date \_\_\_\_\_

Source of Data or  
Person Interviewed \_\_\_\_\_

Position \_\_\_\_\_

1. Who in the Army initiated the request for the study?

\_\_\_\_\_ AIC \_\_\_\_\_  
\_\_\_\_\_ System Project Office \_\_\_\_\_  
\_\_\_\_\_ Another Command \_\_\_\_\_  
\_\_\_\_\_ Another Service \_\_\_\_\_  
\_\_\_\_\_ Department of the Army Staff \_\_\_\_\_  
\_\_\_\_\_ Department of Defense \_\_\_\_\_  
\_\_\_\_\_ Other \_\_\_\_\_

2. What people were in the chain of the study directive (workstatement) from initiator to the study performer?

3. What was the nature of the directive to perform the study?

4. How many questions were asked?

1      2      3

\_\_\_\_\_



5 How many assumptions or conditions were given?

1            2            3

\_\_\_\_\_

6 Were the alternative systems which were to be considered in the study specified in the directive?

1            2            3

\_\_\_\_\_

7 How much was the directive modified before the study was undertaken?

8 What were the sources and reasons for the change?



9 What alternative organizations were considered for the study?

\_\_\_\_\_ Industry  
\_\_\_\_\_ Not for profit  
\_\_\_\_\_ University  
\_\_\_\_\_ Department of the Army Staff  
\_\_\_\_\_ Department of the Defense Task Force  
\_\_\_\_\_ A particular Army Command \_\_\_\_\_

10. Which group was chosen and why?

\_\_\_\_\_ Time  
\_\_\_\_\_ Particular expertise  
\_\_\_\_\_ Funding  
\_\_\_\_\_ Jurisdiction  
\_\_\_\_\_ Current workload  
\_\_\_\_\_ Other \_\_\_\_\_

11 Who made this selection?

12. Did the chosen study organization have any interest in the decision to be made on the basis of the study?

\_\_\_\_\_ Yes \_\_\_\_\_ No: What \_\_\_\_\_

What was their preferred solution or conclusion.

13 What was the initially estimated cost?



14. What amount of funding was approved?

15. Who made the funding decision?

16. What criteria were used in evaluating the appropriate level of funding for the study? (Agency quote, study priority, Magnitude of decision to be made, availability of staff, scope of task, etc.)





17. What was the actual time and cost required for conduct of the study?

18. How many reviews were made of the validity of the study, by whom?

19. For each review which of the following recommendations were taken?

1	2	3	
_____	_____	_____	Accept the study
_____	_____	_____	Request different methodology
_____	_____	_____	Correct computational error
_____	_____	_____	Request study of other conditions
_____	_____	_____	Request new data be considered
_____	_____	_____	Request parallel study by another agency be made
_____	_____	_____	Request new alternatives be analyzed
_____	_____	_____	Revise interpretation of results
_____	_____	_____	Reject study
		_____	Other _____

20. Why was this recommendation taken?



21. What decision was made after the study?

- ☐ Buy
- ☐ Partial or Pilot buy
- ☐ Test
- ☐ Wait
- ☐ Restudy
- ☐ Reduce a program
- ☐ Terminate a program
- ☐ Change a policy
- ☐ Other \_\_\_\_\_

State in greater detail and why was this decision made.

22. Who was the decision maker and what was his rank and position?



23. What auxiliary studies and decisions were required as a result of the study?

Identify the purpose of each.

24. What were ~~the~~ recommendations of the later studies?

25. Name each study which preceded these studies.

26. What was the outcome of each?



27. What actions were taken subsequent to the initial decision? Give dates  
for each action?

28. To what extent were the assumptions and conclusions of the study borne  
out in later events?

29. Was the decision later reversed?

\_\_\_\_\_ yes \_\_\_\_\_ no

30. When was the first study in this series initiated?

31. When was the last study completed?





### Attachment 3

#### List of Studies with Suitable Identification

1. Cost/Performance Analysis of M656, M520, M54A2 and M548 Vehicles, August 1967, U. S. Army Materiel Command
2. A Cost and Effectiveness Evaluation of Sand Bag Textiles (U) December 1967, Memorandum Report No. 1882, BRL, RDT & E Project No. 1P523801A098
3. M561 Cost Effectiveness Study, Revised September 1966, Technical Study EEB-662, U. S. Army Tank-Automotive Command
4. Parametric Analysis of Pershing QRA Alternatives (U), March 1967
5. Cost-Effectiveness Analysis of a Non-Nuclear Sergeant (U), 8 November 1966, Revised 18 October 1967, Report No. RF-TR-66-2, DA Project No. 1X279191D687, U. S. Army Missile Command, Redstone Arsenal, Alabama
6. An Effectiveness Comparison of 4.2" Mortar Ammunition M329A1 VS. XM571 (U), June 1967, Technical Note No. 1661, RDT & E Project No. 1P523801A098, BRL
7. A Single Versus Twin Engine Helicopter Troop Carrier Study (U), 19 January 1968, Technical Report 02015.04-1, Contract DA-49-186-AMC-393(X)0, Vitro Laboratories, Silver Spring, Maryland
8. Exhibits Law Workshop (U), 7 July 1967, Revised Summary Report Law Workshop (U), 22 September 1967 (This report supercedes report dated 7 July 1967)
9. Reval Wheels (Re-evaluation of the Army Tactical Vehicle Program) Final Report, 1 March 1968, Assistant Chief of Staff for Force Development
10. A Study of the Medium AntiTank/Assault Weapon (U), August 1963, Memorandum Report No. 1488, RDT & E Project No. 1M523801A286, BRL



11. Technical Review of Army Air Defense System (TRAADS), 15 March 1968, Technical Review of Army Air Defense RDT & E Program Review Plan 28 December 1967 U. S. Army Missile Command

12. Advanced Forward Area Air Defense Systems Study Phase 1 (U), 15 March 1966, Report No. RD/RE-SS-66-1, U. S. Army Missile Command

13. Parametric Design/Cost Effectiveness Study for a Mechanized Infantry Combat Vehicle-1970 (MICV-70) (U), Final Report Vol. 1-3, Report No. GM-2144-H-1b, Contract DA-11-199-AMC-651(W), November 1966, Cornell Aeronautical Laboratory. Also, Cost Effectiveness Analysis of a Strong Anti-Armor Capability for MICV-70 (U), Final Report, 30 June 1967

14. Dispersions for Effective Automatic Small Arms Fire and a Comparison of the M-14 Rifle with a Weapon Yielding Effective Automatic Fire (U), January 1961, Technical note No. 1372, BRL (not complete)

15. A Cost/Effectiveness Study of Mobile Utility Module System (Mums 18-5), March 1968, U. S. Army Mobility Equipment Command (not complete)

16. An Operational and Cost Effectiveness Study of the Lance Missile System, Combat Development Command and Army Materiel Command, April 1965, Vol. I-VI

17. Study, Optimum Mix of Artillery Units 1971-1975, Combat Development Command, July 1967

18. Re-optimization of a Multiple Artillery Rocket System--Mars II, BRL, May 1964



Attachment 4

Ranking of Studies Based on Composite Index

Reval Wheels Excellent

Redleg

Pershing

- - - - -

Sandbag Very Good

Law

Mars II

Traads

- - - - -

Lance Good

Twin vs. Single

FAAADS

Grenade Launcher

- - - - -

MAW Adequate

MICV-70

M 656

M561

Mortar

- - - - -

Attachment 5

Ranking of Studies Based on Composite Index

Excellent	Level 100%
	Bedding
	Finishing
	-----
Very Good	Landings
	Low
	Moisture
	Trunks
	-----
Good	Landings
	Trunks
	-----
Adapted	Moisture
	Trunks
	-----
	Moisture
	Trunks
	-----









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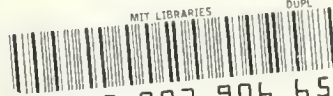


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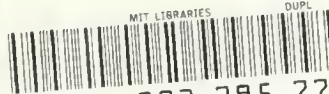


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